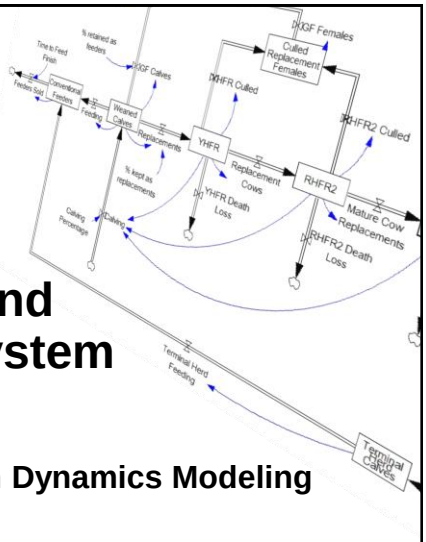
Building Models for Animal Production and Management with System Dynamics Modeling



A Basic Introduction to System Dynamics Modeling

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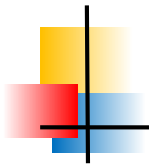
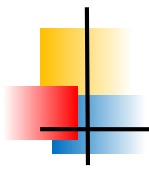
Learning Objectives

- Be able to define:
  - System dynamics,
  - Stocks, flows, and converters/auxiliaries,
  - Mental model.
- Be able to build a small dynamic model.
- Be able to run a model experiment and explain the change in dynamic behaviors.
- Gain appreciation for ways systems analysis with models can help address complex problems.



Agenda

- System Dynamics overview ≈15-20 min.
- Laboratory with a small model ≈45-50 min.
- Case study of integrated beef-production system problem ≈15-20 min.
- Items not discussed: units checking, data integration, model calibration & evaluation, or sensitivity analyses



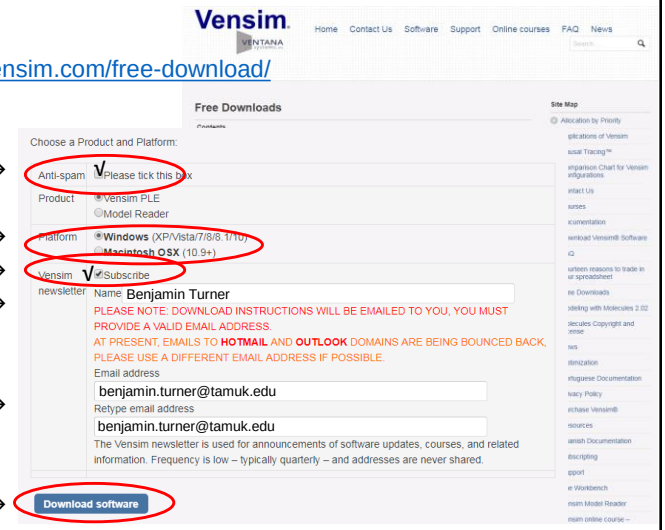
What you need:

- Laptop with Vensim PLE running
- The file named *"small herd profit model.mdl"*
- Handouts

What you need:

To get Vensim PLE

- Go to https://vensim.com/free-download/



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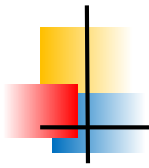
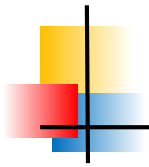
Rationale

- Complex [feedback driven] interactions pose challenges for designing effectively strategies and policies to improve societal food and nutrition outcomes
- Due to this complexity, involving multiple disciplines/industries must be considered in tandem
- "Systems perspective" increasingly recognized as valuable approach to achieve goals, but is often "glossed over" in implementation
- System Dynamics (SD) provides rigorous, scientific method to fill the gap between aspiration of "systems perspective" and the reliance on reductionist approach



Consider this…

- A landowners coalition lobbies government to support water diversions from a river system to irrigate crops.
- Downstream from landowners, the river flows into a wildlife refuge, which is habitat to an endangered species.
- You are hired to provide an assessment of the impact of water diversion on the endangered species.



Consider this…

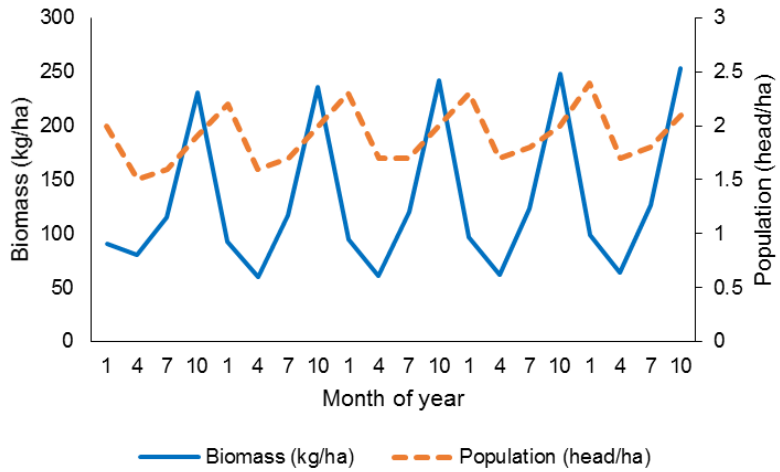
- Assumptions:
  1. Permit will be approved.
  2. Develop guidelines: relative impacts of diverting different quantities of water during different seasons.
  3. Landowners plant 100 kg/ha/yr.
  4. Diversions will amount to 15% of river flow for entire year.

Data

Year	Month	Native biomass (kg/ha)	Population (animal/ha)
1	1	90	2.0
	4	80	1.5
	7	115	1.6
	10	231	1.9
2	1	93	2.2
	4	60	1.6
	7	117	1.7
	10	236	2.0
3	1	95	2.3
	4	61	1.7
	7	120	1.7
	10	242	2.0
4	1	97	2.3
	4	62	1.7
	7	123	1.8
	10	248	2.0
5	1	99	2.4
	4	64	1.7
	7	126	1.8
	10	253	2.1

- Endangered species and the food and habitat it depends on.
- Collected at 3 month intervals over last 5 years.

Data

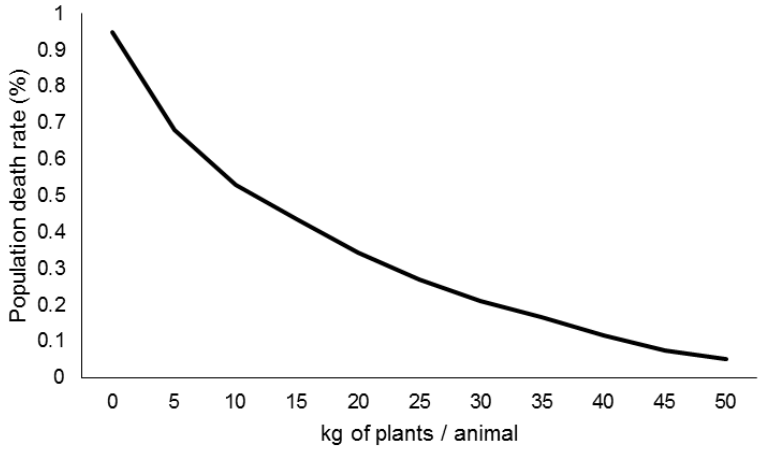


Data

- Animal deaths as a function of per capita food availability.

Proportion of pop. dying	Kg. of plants per animal
0.95	0
0.68	5
0.53	10
0.435	15
0.345	20
0.27	25
0.21	30
0.165	35
0.115	40
0.075	45
0.05	50

Data

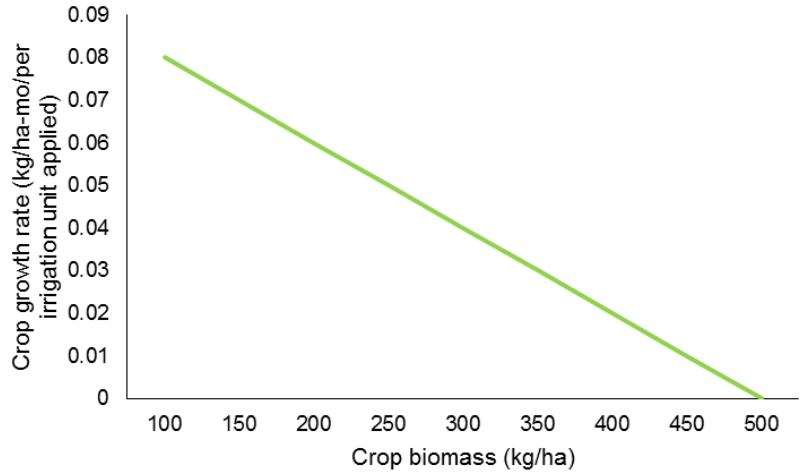


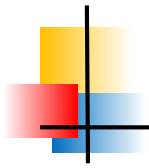
Data

- Growth rate of crops per unit of standing crop that results from each unit of irrigation water received during month.

Crop growth rate (kg/ha-mo. per irrigation unit applied)	Crop biomass (kg/ha)
0.08	100
0.07	150
0.06	200
0.05	250
0.04	300
0.03	350
0.02	400
0.01	450
0.00	500

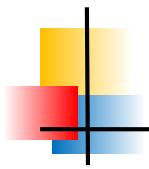
Data





So…

- What guidelines concerning water diversion would you suggest?
  - Can the landowners divert 15% of the river flow for irrigation during the entire year without negatively affecting the endangered species in the refuge?
  - What are the relative impacts (both on endangered species and crop production) of diverting different quantities of water during different seasons?
  - On what type of analysis would you base your recommendations?



Rationale

- Predicting the dynamics of even relatively simple systems for which we have a solid database is no trivial matter.
- Understanding the behavior of each part of the system does not guarantee an understanding of the behavior of the system as a whole.
- The most pressing problems we face as managers deal with inherently complex systems.
- Unintended consequences abound…

What is System Dynamics?

- System Dynamics (SD)- an interdisciplinary method to enhance learning in complex systems, grounded nonlinear dynamics and feedback control theory, in order to solve real-world problems.
- What makes it unique?
  - Both a set of **mathematical applications** in tandem with a particular **perspective (mental model)** of the process and interpretation of how to address complex problems
  - Perspective- problem (not system) focused, using both "hard" and "soft" feedback structures that drive behavior-over-time

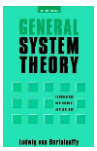
Genesis of Systems Analysis

Father of System Theory

Ludwig von Bertalanffy (1901-1972)

$$l_t = L_\infty[1 - e^{-k(t-t_0)}],$$

von Bertalanffy growth equation



Father of System Dynamics

Jay Forrester (1918-2016)

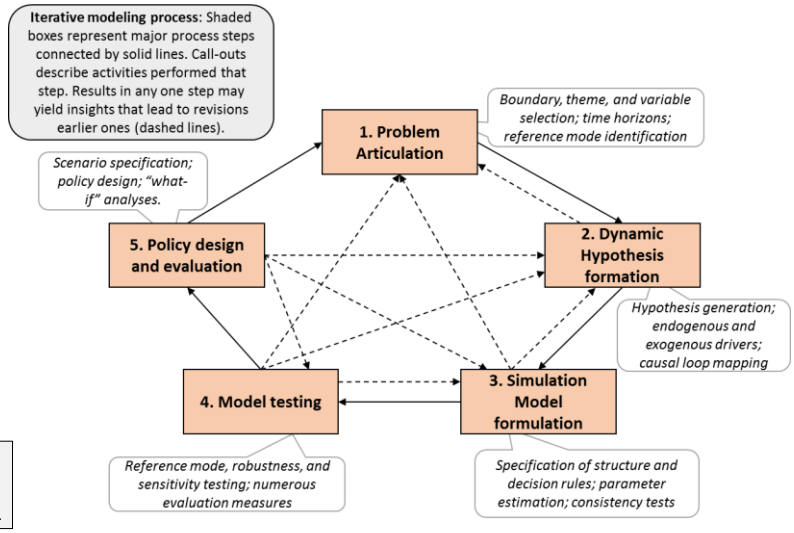
- Ranching influenced
- Aided in WWII to develop feedback technology.

Peter Senge (1947-)

John Sterman (19--)

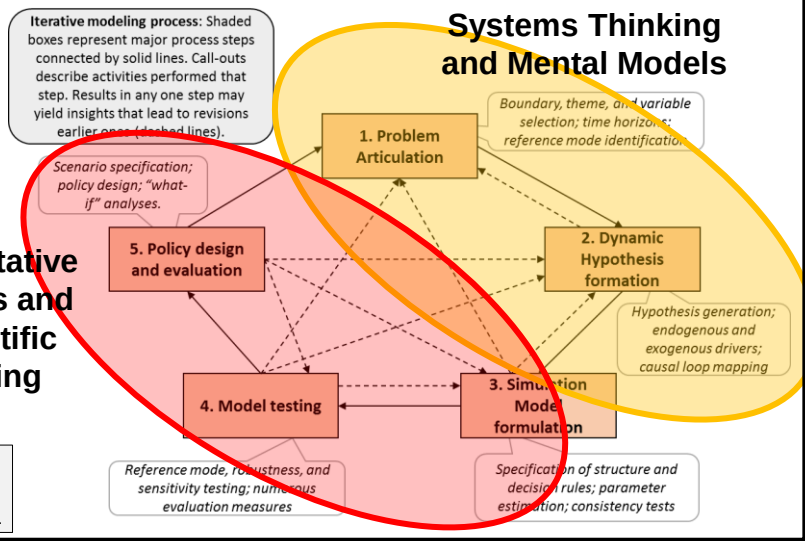
"The Fifth Discipline", "Business Dynamics", influential in computer simulations development

SD Modeling Process



Adapted from Sterman, J.D. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World.* McGraw-Hill, Boston, MA.

SD Modeling Process



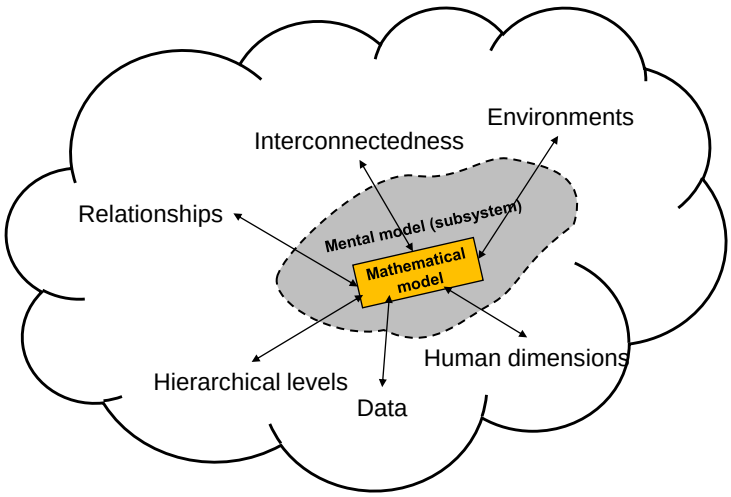
Adapted from Sterman, J.D. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World.* McGraw-Hill, Boston, MA.

Mental Models

- The beliefs, assumptions, and models we have are about every aspect of ourselves, others, our organizations, and how the world works.
  - They are critical to our effectiveness.
  - They affect how we think and how we act.
  - They may be conscious, or unconscious; they can get us into trouble.
  - It's easier to see others' mental models and harder to see our own.
  - They are always incomplete and often flawed.
  - They are high leverage.

Mental Models

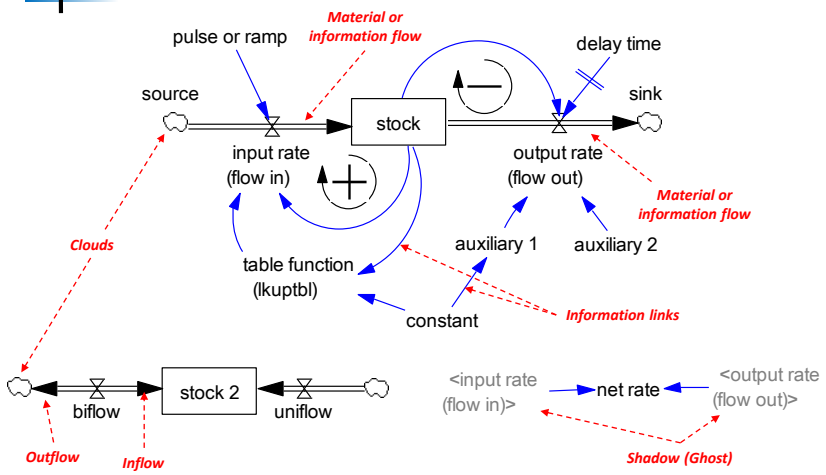
System =



Systems Analysis Terms

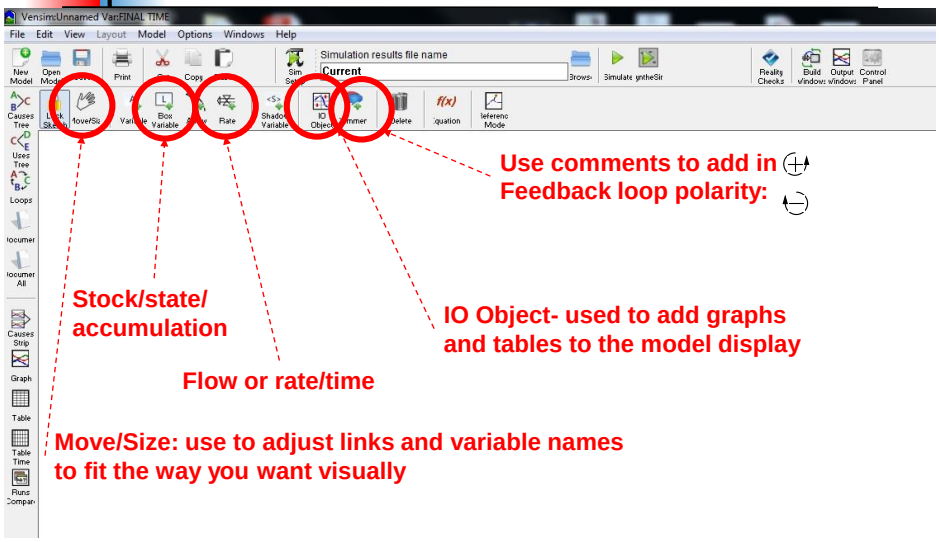
- Models and Diagrams
  - **Stocks** (or state variables or accumulations) are the major concerns which change through time (e.g., population size; biomass).
  - **Flows** (or rate variables) represent flows/movement of material or energy between state variables and characterize the rate of change of these state variables as a result of specific processes.
  - **Information links** between variables are established by **auxiliary** variables (**converters**).

Systems Analysis Terms



Turner, B.L., Menendez, H.M, Gates, R., Tedeschi, L.O., Atzori, A.S. 2016. System Dynamics Modeling for Agricultural and Natural Resource Management Issues: Review of Some Past Cases and Forecasting Future Roles. *Resources* 5(4), 40, doi:10.3390/resources5040040

Vensim interface



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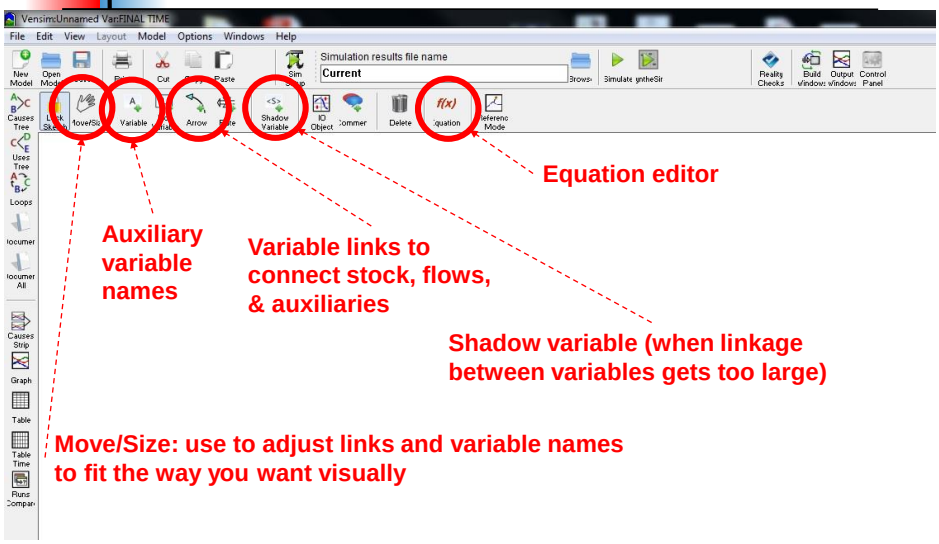
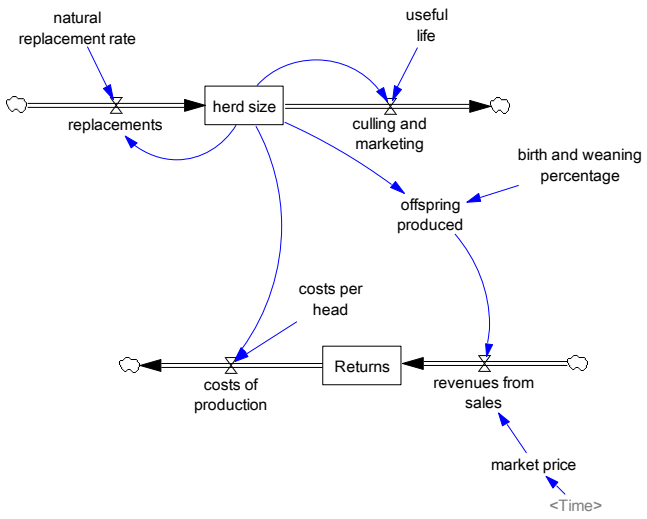


Hands on simulation with the *small herd profit model*

Hands On Simulation

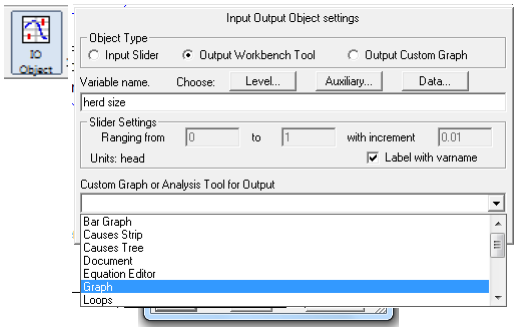


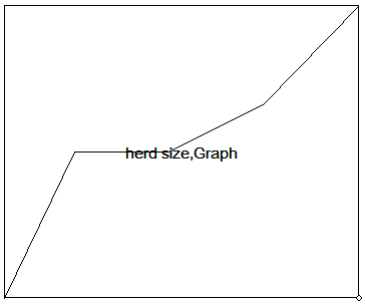
Hands On Simulation

- Build and test a small model (part 1)
  - Problem or Goal: Manage a livestock herd such that Returns are maximized and the herd size is able to grow.
  - Costs are driven by the number of animals in the herd.
  - Revenues are based on the number of offspring and seasonal market prices.
  - Time horizon = 120 months
  - Time step = 1 month
  - Explore the model and add graphs for *herd size* and *Returns*.
  - Run the model and examine its behavior. Note the ending values for *herd size* and *Returns*.

Hands On Simulation

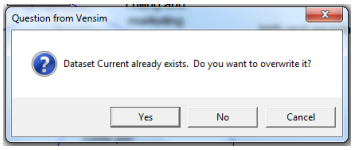
- Part 1 Adding graphs.

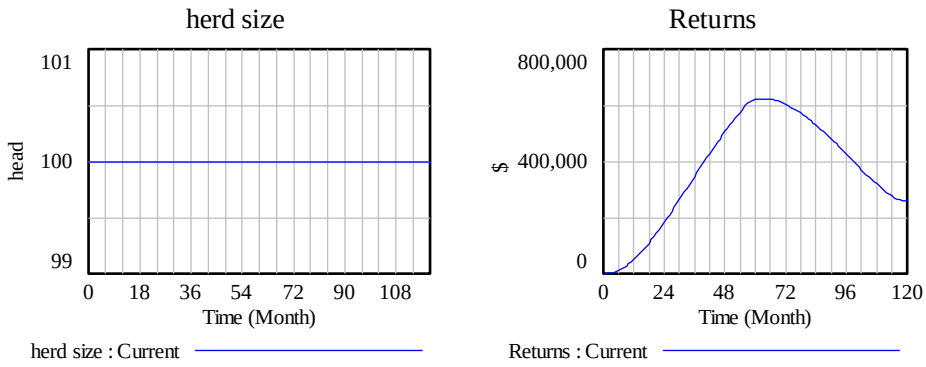




Hands On Simulation

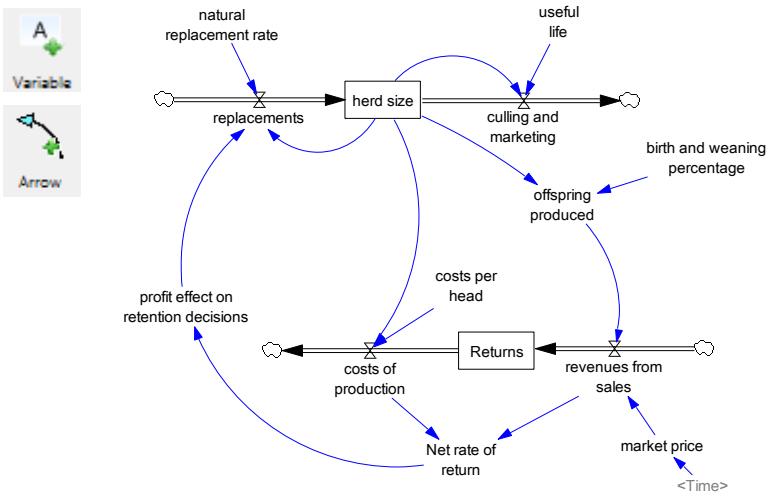
- Part 1 Results





Hands On Simulation

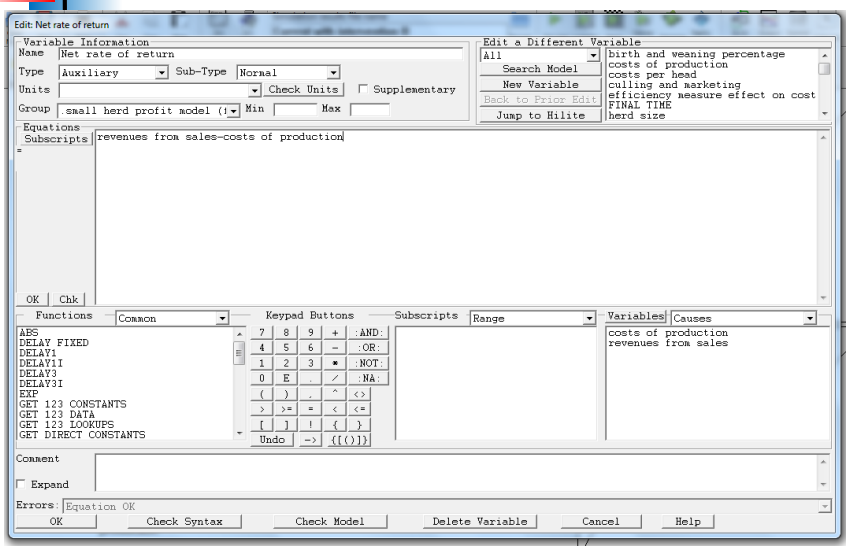
Part 2: Adding structure



Hands On Simulation

- Part 2: Adding Structure
  - Add an auxiliary variable called *Net Returns = Revenue from sales – costs of production*

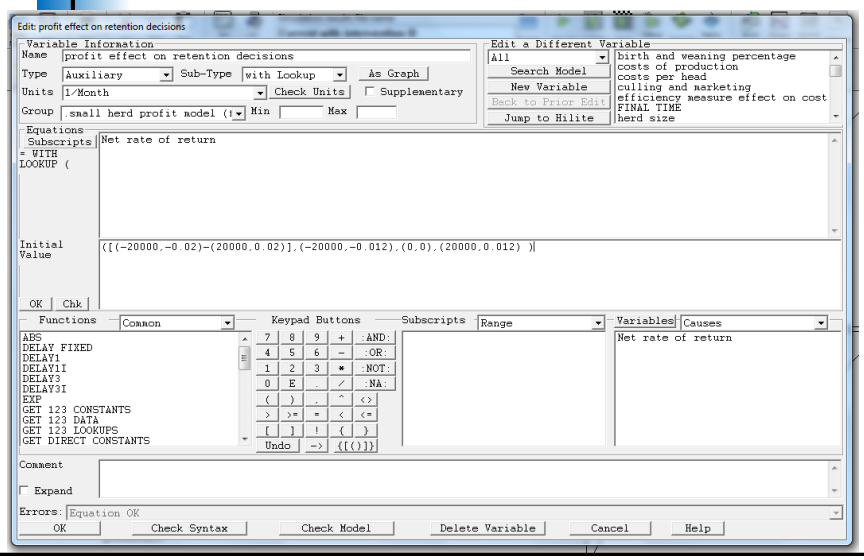
Hands On Simulation



Hands On Simulation

- Part 2: Adding Structure
  - Add an auxiliary variable called *Net Returns = Revenue from sales – costs of production*
  - Add an auxiliary variable called *profit effect on retention decisions*.
    - Variable type: Auxiliary
    - Sub-Type: With Lookup
    - = *Net Returns*
    - Click “As Graph”, input the following: (-20,000, -0.0012), (0, 0), (20,000, 0.0012). Click OK → when prompted to add a link, click OK

Hands On Simulation



Hands On Simulation

- Part 2: Adding Structure
  - Add an auxiliary variable called *Net Returns = Revenue from sales – costs of production*
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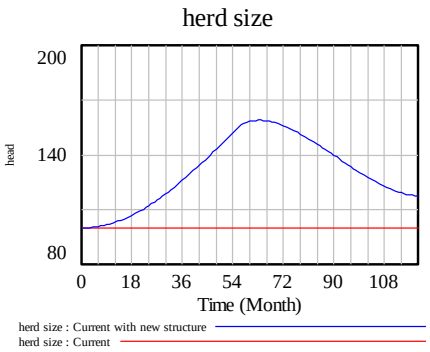
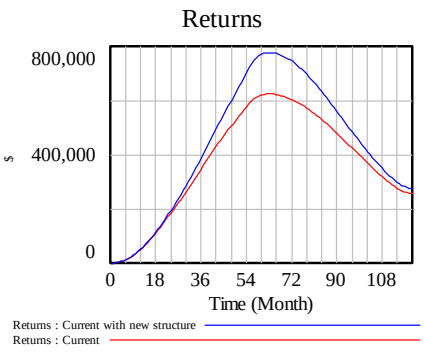
    - Variable type: Auxiliary
    - Sub-Type: With Lookup
    - *= Net Returns*
    - Click "As Graph", input the following: (-20,000, -0.0012), (0, 0), (20,000, 0.0012). Click OK → when prompted to add a link, click OK
  - Add a link from *profit effect on retention decisions* to *replacements*
  - Adjust *replacements = herd size*(natural replacement rate + profit effect on retention decisions*)
  - Rename the simulation "*Current with new structure"*
  - What is the expected behavior pattern now?
  - Run the model and examine its behavior.

Hands On Simulation

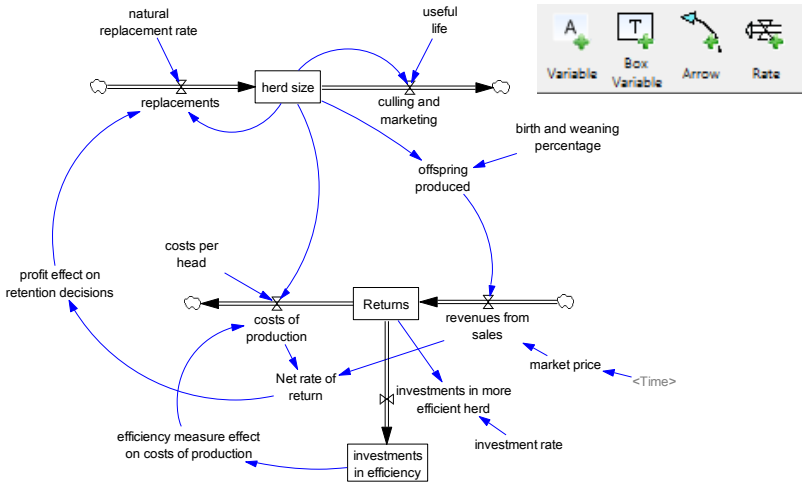
- Part 2 Results





Hands On Simulation

Part 3: New strategies or interventions

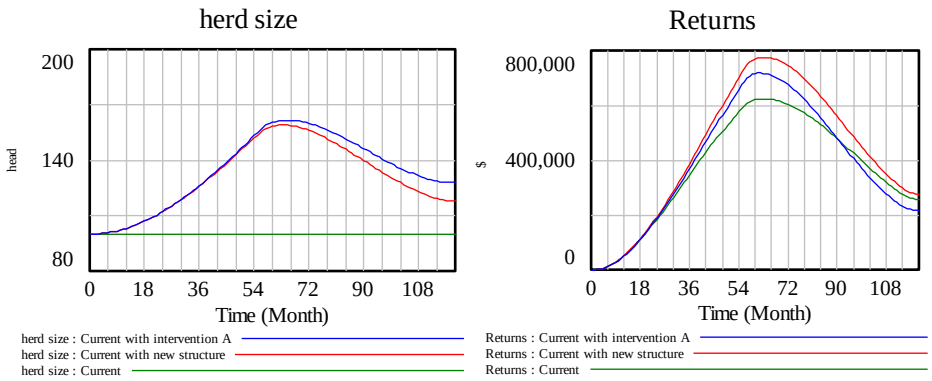


Hands On Simulation

- Part 3: New strategies or interventions
  - Add a stock below *Returns* called *Investments in efficiency* (initial value = 0)
    - Add an auxiliary variable called *investment rate* = 0.0042.
    - Using a flow, connect *Returns* to *Investments in efficiency*.
    - Name the flow *investments in more efficient herd*.
    - Connect *investment rate* and *Returns* to *investments in more efficient herd* (=*Returns***investment rate*)
    - Check the new stock to make sure it is complete.
  - Add an auxiliary variable called *efficiency measure effect on costs of production*.
    - Type: Auxiliary
    - Sub-type: With Lookup
    - = investments in efficiency
    - Click “As Graph”, input the following: (0, 0), (1,000,000, -0.25). Click OK.
  - Connect *efficiency measure effect on costs of production* to the flow *costs of production* [= *herd size**(*costs per head**(1 + *efficiency measure effect on costs of production*))] . Click OK.

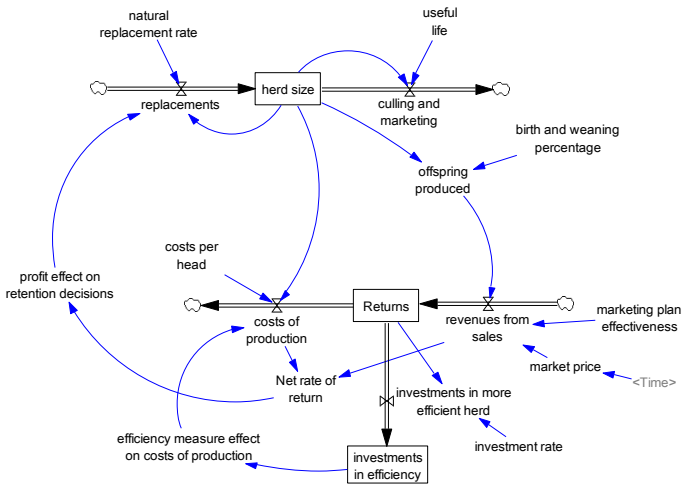
Hands On Simulation

- Rename the simulation "*Current with interventions A*"
- Part 3 Results- What are the expected behaviors now?



Hands On Simulation

Part 4: Reinvestment strategy

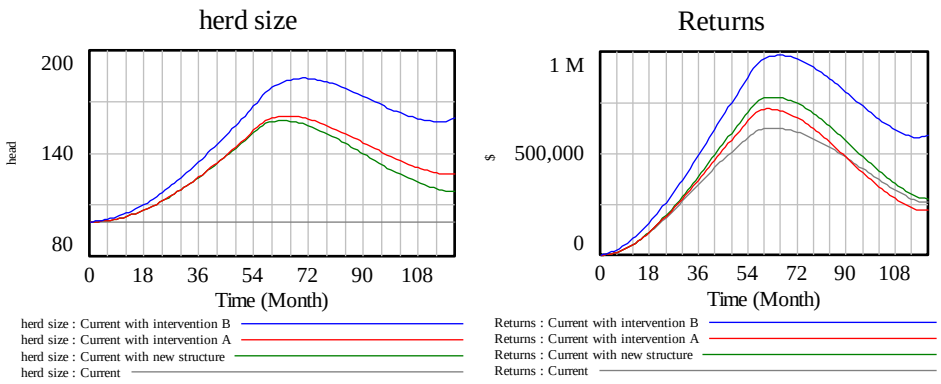


Hands On Simulation

- Part 4: New strategies or interventions
  - Use the cost savings to employ a value-added marketing strategy.
  - Add an auxiliary variable next to market price called *marketing plan effectiveness* = 1.05
  - Connect *marketing plan effectiveness* to the flow of *revenues = offspring produced*(market price*marketing plan effectiveness*)
  - Rename the simulation "*Current with intervention B*"
  - What are the expected behavior patterns now?
  - Run the model and examine the behaviors.

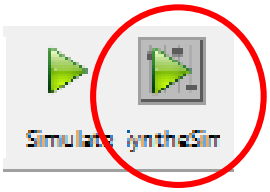
Hands On Simulation

- Part 4 Results



Hands On Simulation

- What would it take to double the herd size from 100 to 200 in ten years?

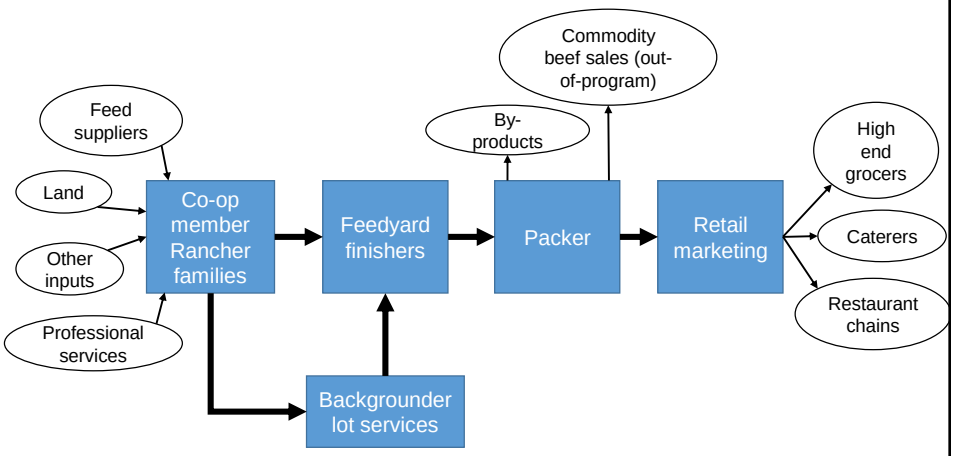


Advanced case study

Why is morbidity increasing over time in our integrated beef production system?

Rancher-owned business providing value-added beef directly to consumers.

About the case

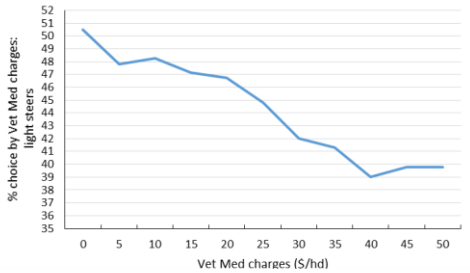


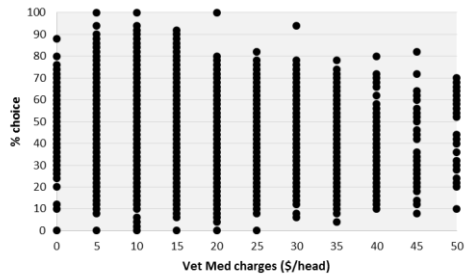
Observable data

Observable data

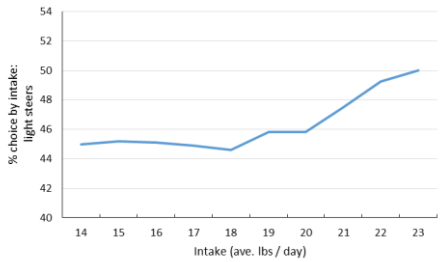
- Ave. morbidity in feedlots 15%
- Cattle aren't sick at home ranches
- Cost $200,000+ to system
- Some members' cattle have the problem, others don't
- Lost rancher premiums for sick cattle
- Feedlot backlog in processing: 15,000 head

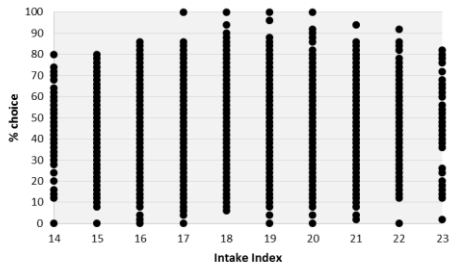
Trends and Patterns





Trends and Patterns

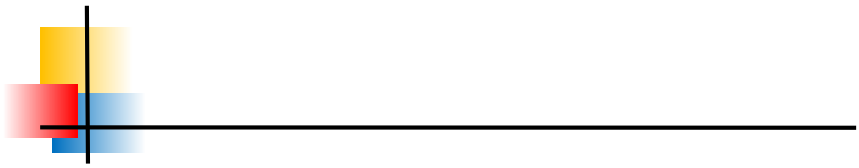




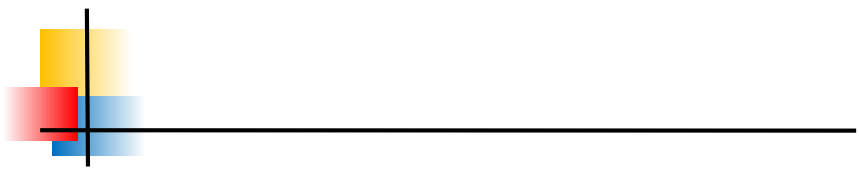
Assumptions Made

“It’s somebody else’s problem”

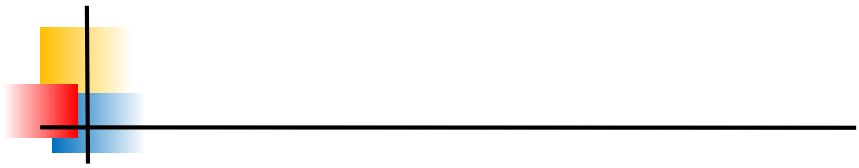
“I’m doing everything I can”



Conclusions



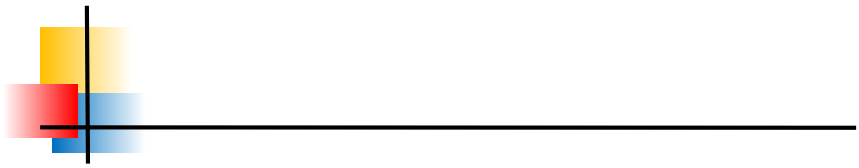
“Feedlot is the cause of the problem.”



Beliefs

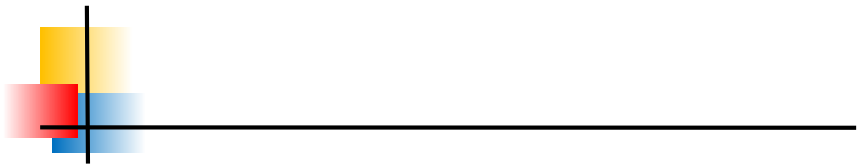
“All for 1 and 1 for all!”

“Rancher welfare is more important than the system.”



Actions

Insurance Program

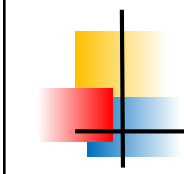


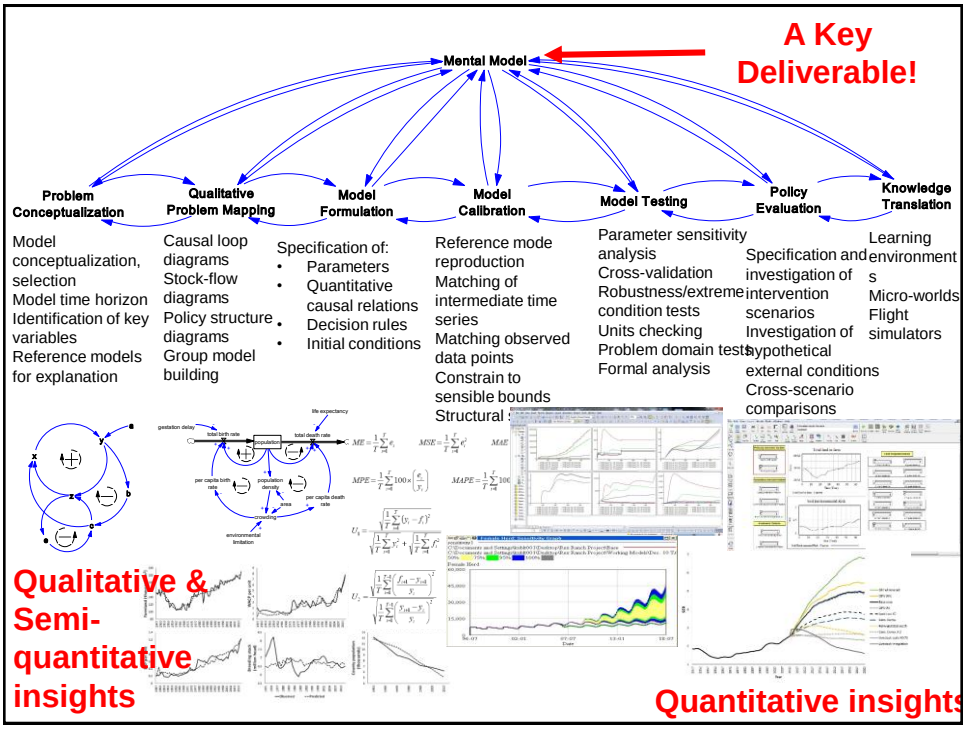
“When a cow gets sick and receives antibiotics, it gets tagged, pulled out of the natural beef category and sold in the commodity market. The OP condition is believed to more frequently occur with newer, less experienced ranchers and those ranchers who have to transport animals over long distances to get to the feedlot. Another theory was that newer members generally have to place their cattle in the feedlot during winter when it is trickier to achieve efficient weights and severe temperature swings over trucking routes put more stress on the cattle…. The ranchers also wondered what could happen at the feedlot when cattle from different ranches mingle.”

"After hours of discussion, an "OP (out-of-program) insurance" plan was approved where ranchers and the company paid premiums into the program which would reimburse ranchers who encountered an above average level of OP cows."

OP insurance: placed additional cattle in the feedlot to serve as insurance, ranging from 1,000 head in the summer to 3,000 during the winter

Reinforcing problem structure?





Thank you!